MFR PAPER 1113

Culture of the Bay Scallop, *Argopecten irradians*, in Virginia

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INTRODUCTION

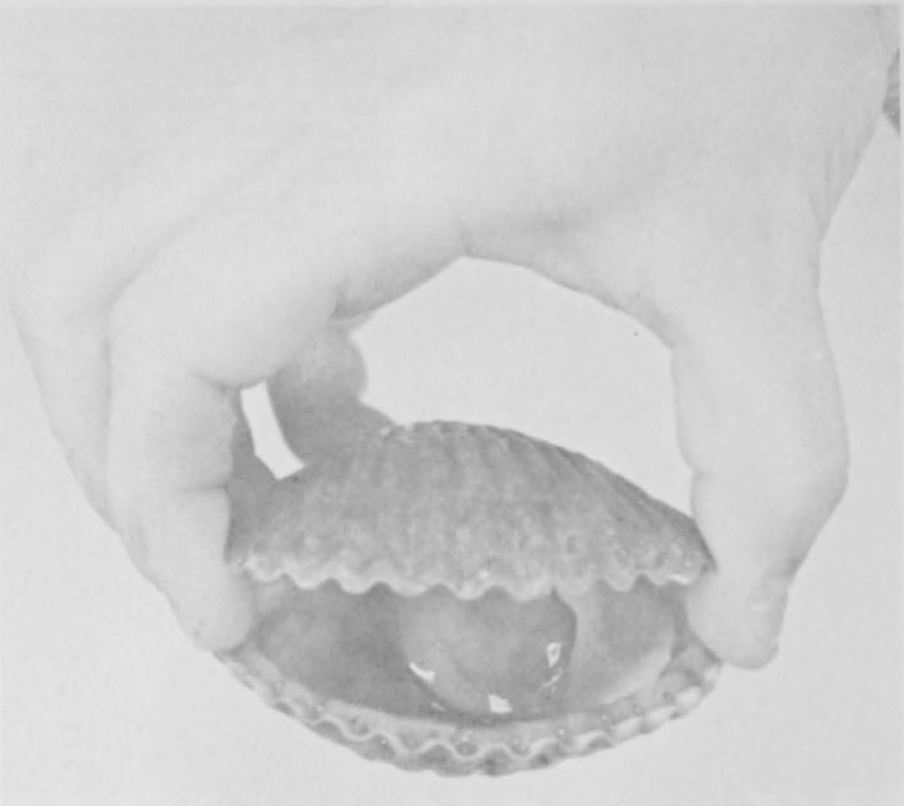
In recent years there has been an increased interest in the development of marine aquaculture or mariculture. Techniques for growing many traditional species, such as oysters and quahogs, have been developed, and considerable effort has also been made to test the feasibility of culturing new, less traditional species (Loosanoff and Davis, 1963; Iversen, 1968; McNeil, 1970; Price and Maurer, 1971; and Milne, 1972). This paper reviews the natural history of the bay scallop, *Argopecten irradaians* Lamarck, and presents a review of the Virginia Institute of Marine Science's (VIMS) continuing research on this species which began in 1968.

The bay scallop has several characteristics well suited for mariculture. It is fast growing, easy to condition and spawn, and is relatively hardy throughout all life history stages. Most important, it has a good market demand and commands high prices. Many species are biologically amenable to mariculture, but economics dictate the use of gourmet species which command high prices to defray high costs of culture.

Only adductor muscles of scallops are utilized. Yields vary, but approximately 1-1¼ bu of scallops produces 1 gal (9 lb) of adductor muscle. The price of shucked scallops rose to $38 per gal (for adductor muscles) in 1973, or over $4.20 per lb, certainly qualifying scallops as a gourmet food.

Utilization of shell and viscera would not significantly change the price or the demand. A mechanical

Bay scallops (*Argopecten irradians*), top photo, grew from 16 to 57 mm in size in pen in Assateague Channel from 9 July to 24 November 1970. Shucked, lower photo, 247 of these scallops yielded approximately 1 qt adductor muscle.



Scallop, showing developing gonad.

shucking and eviscerating machine developed for the calico scallop fishery along the southeast coast of the United States could be used on bay scallops (Webb and Thomas, 1971). This would markedly reduce manpower and cost problems associated with hand shucking.

Bay scallops retain the ability to swim at all sizes, making it necessary to confine them in suitable enclosures. Although this necessity increases expenses, it is partially compensated by reducing the cost of harvesting expenses.

NATURAL HISTORY

The natural history of the species has been described by Belding (1910), Wells (1927), Gutsell (1930), Loosanoff and Davis (1963), Sastry (1965), and Castagna and Duggan (1971). Bay scallops in the mid-Atlantic area spawn from mid-April through early September (Chanley and Andrews, 1971). Spawning in New England occurs when water temperatures reach 22-26°C (Belding, 1910). Although the scallops are hermaphroditic, self-fertilization is uncommon in nature (Belding, 1910; Gutsell, 1930). They usually release sperm first, followed by eggs (Loosanoff and Davis, 1963), which encourages cross-fertilization. Fertilized eggs develop into straight-hinge veligers in a few hours, and the larvae are planktonic for about 5-8 days. Longer larval periods are common when environmental conditions are less than optimum. The total length of the straight-hinge stage ranges from 85 μ minimum to 140 μ maximum (Chanley and Andrews, 1971).

Juveniles attach by byssal threads to eelgrass or other epibenthic support. They usually maintain attachment until 20-30 mm size is reached, after which most scallops drop to the bottom. Marine plants or other suitable cover is quite important to scallops. Small scallops (under 10 mm) do not survive well when exposed to silt. By attaching to the leaves or stems of submerged plants, they grow large enough to survive the more rigorous existence and greater exposure to silt on the bottom. Further, grass beds reduce current velocities. Work by Kirby-Smith (1972) indicates that scallops grow faster in slow currents. Maximum growth rates were achieved in 1-5 cm/sec, and a flow volume of 4 liters/hr/scallop the slowest current velocities tested. Scallops apparently retain their ability to form byssal attachment throughout their lives, but are seldom found attached when fully grown. They are active swimmers at all sizes and apparently use this ability to avoid predators such as starfish and crabs. Davis and Marshall (1961), studying the filter feeding of bay scallops, found an abundance of benthic and tychpelagic diatoms in the stomachs. They considered this an indication that much of the food is microflora, detritus, bacteria, and organic matter that is common in the water immediately adjacent to the bottom.

The bay scallop has a relatively high pumping rate, probably correlated with its rapid rate of growth. The average rate for small scallops, 38-44 mm in length, was 3.26 liters/hr. The larger scallops, 64-65 mm in length, averaged 14.72 liters/hr, with a maximum rate of 24.4 liters/hr (Chipman and Hopkins, 1954).

The average lifespan is about 12-16 mo with a few individuals surviving to 18 mo and rarely even to 24 mo (Belding, 1910). The scallop, typical of animals with short life cycles, exhibits great fluctuations in abundance.

MATERIALS AND METHODS

The procedures used by VIMS scientists for conditioning and spawning scallops and handling larvae were similar to those used by Loosanoff and Davis (1963). Stocks of spawners were collected from the seaside of Eastern Shore and from North Carolina. Scallops were grown in pens and floats built of plastic screen stretched over wooden frames. Measurements of scallops were from hinge to lip.

Seawater used in the laboratory was pumped from an adjacent creek by cast-iron pumps. All pipes and containers were plastic or glass. The seawater used for larvae and early juveniles was clarified by centrifugation in a Sharples[1] clarifier, Type AS-14, or a Westfalia separator, Model KDD 605. The average salinity for

[1]Reference to trade names does not imply endorsement of commercial products by the National Marine Fisheries Service, NOAA.

the experimental area was 29.5 $^0/_{00}$ with seasonal temperatures ranging from 3 to 28°C.

CONDITIONING FOR SPAWNING

The scallops were conditioned by placing them in aerated standing seawater at temperatures of from 18 to 22°C for 3-6 wk depending on food, temperatures, and the initial gonadal condition of the scallops (Castagna and Duggan, 1971). The conditioning was usually done on scallops taken from ambient-temperature seawater, which dropped as low as 3°C in winter. While held in standing water, the scallops were fed mixed algal cultures. The maturation of the gonads could be seen by holding the valves slightly open. The gonad is a triangular bulbish organ lying alongside the adductor muscle. When ripe, it is usually a red-orange color (often covered by a black epithelium). The testis comprises the white anterior border of the gonad (Castagna and Duggan, 1971).

SPAWNING

Spawning was accomplished by placing one or two adult scallops in a 1-liter Pyrex container filled with filtered seawater. A number of these containers were placed in a water table. By flooding the water table with hot or cold water, the scallops were subjected to temperature changes sufficient to induce spawning. Temperatures of 24-26°C induced maximum pumping activity. Temperatures were usually raised to 30°C for a few minutes and then dropped back to 24°C. Spawning usually took place at 28-26°C.

A sperm suspension (either stripped or spawned) was added to further stimulate scallops to spawn. Various chemical stimulants have been tested with little or no success. Both sex products are often released by the same scallop but usually not simultaneously.

After spawning the scallop was removed from the dish and the egg suspension was poured through a screen, to remove dirt and fecal material ejected by the spawner, into a calibrated container of filtered seawater. Eggs were counted by stirring the contents of the container and subsampling several 1-ml samples. An estimate of the number of eggs was made by averaging the counts and multiplying by the total volume.

Scallop in foreground (left) is spawning.

FERTILIZATION

Fertilization was initiated by adding approximately 6 ml of sperm suspension per liter of egg suspension. Fertilization was nearly 100 percent successful even when sperm and eggs from the same individual were used. The addition of too much sperm suspension can cause larval deformities, probably due to polyspermy.

DEVELOPMENT

Survival and development were usually enhanced by holding developing eggs above 20°C. Optimum temperature for development appeared to be 26-28°C. A minimum salinity of 22.5 $^0/_{00}$ was necessary for development to straight-hinge stage. At near-optimum temperature in 28-30 $^0/_{00}$ salinity, the blastula stage was reached in about 4 hr, trochophore stage in 8-12 hr, and straight-hinge stage in 16-24 hr. The embryonic stages preceding the straight-hinge stage were most vulnerable to environmental conditions, but with proper maintenance approximately 60 percent survival can be expected. Larvae from self-fertilized eggs usually appeared normal in the F_1 generation. Subsequent generations often had larval deformities and poor survival.

The larvae were grown in 60-liter plastic containers. Three times a week the water was siphoned from these containers through a fine nylon screen to retain larvae. These were concentrated in calibrated containers of filtered seawater, subsampled, and counted by the same procedures previously described. Measurements of a small sample were taken using an ocular micrometer, and the general condition of the larvae was ascertained. The larvae were then redistributed to containers of clean filtered seawater containing food and, if necessary, antibiotics.

LARVAL DENSITY AND LARVAL ENVIRONMENT

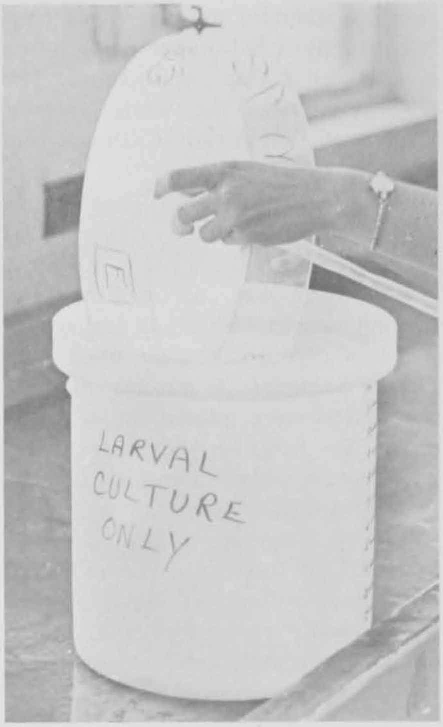
Larval density, although not critical, influenced the success of a group of larvae. Since labor and space were often in short supply, it was tempting to crowd as many larvae into as few containers as possible. This practice increased the number of failures, perhaps by increasing chances of disease transmission or because of competition for food or space. To avoid these problems, cultures were started at maximum densities of 40 eggs per ml. As the larvae grew, their densities were reduced with each water change until densities of 5 per ml were reached when larvae were ready to set.

Aeration was not necessary for survival at the densities stated above. Gentle aeration enhanced growth rate and survival of late larval stages but made little or no difference in small or early larvae. Since scallop larvae set at a relatively small size, aeration was not used routinely.

FOOD

Several unicellular cultures of marine flagellates or diatoms were tried as larval food with varying degrees of success. In all trials, mixtures of two or more species worked better than one species. No artificial food mixture was found that gave comparable results.

Some successful species used were *Monochrysis lutheri*, *Isochrysis galbana*, *Phaeodactylum tricornutum*, *Dunaliella tertiolecta*, and *Nanochloris oculata*. Even though food was added, the water was changed periodically to cleanse cultures of metabolic wastes and dead larvae.



In top photo, a technician washes scallop larvae into container for counting and measuring. A technician grades scallop larvae in the lower photo.

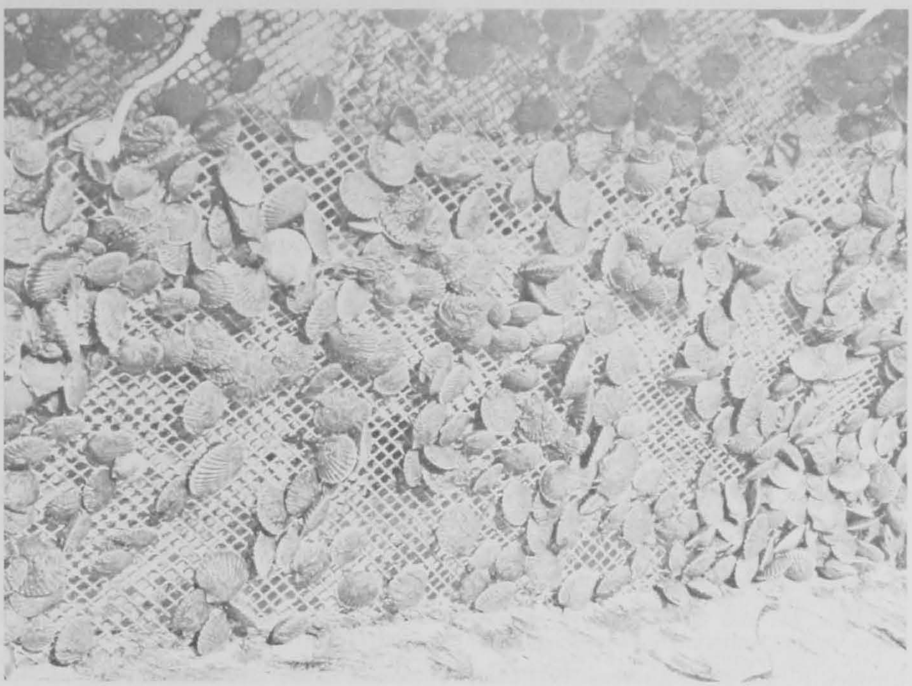
When raising large numbers of scallops (or any other cultured filter feeder), the logistics of growing sufficient unicellular algae become a serious problem. An excellent method of growing quantities of food is the solarium method, often referred to as the Glancy method. (Joseph Glancy, Sayville, N.Y. was the biologist responsible for introducing this method.) This method consists of clarifying and holding seawater in aerated vats in sunlight in a solarium or greenhouse. The stored water develops a bloom of diatoms and flagellates which can be used as food.

The greenhouse method was used successfully at VIMS. Seawater was run through an AS-14 Sharples clarifier, which spins the water at 15,000 rpm in an 8-in diameter tube exerting 13,200 × *g*. Essentially a clarifier separates heavier particles by centrifugal force instead of gravity. The clarified seawater was then stored in 4 × 8 × 4-ft fiberglassed plywood tanks in a solarium and was continuously gently aerated. The clarified seawater retains small diatoms, flagellates, and protozoans. Heavier and larger forms, including zooplankters and diatoms with dense or heavy tests, are left on the wall of the clarifier tube. When stored in a solarium, the water temperature in the large aerated ranks rises, and the small diatoms and naked flagellates reproduce in a bloom that eventually colors the water. Seawater treated in this manner was referred to as cultured water and was used as a medium in which to grow larvae and early juvenile stages. No additional food was required. The cultured water was normally held 24 hr before use. This was sufficient time for a bloom to occur. If stored water was not used in 48 hr, it was usually discarded, since new cultured water resulted in faster growth and better survival of the larvae. Fertilization or inoculation was not necessary to attain dense blooms of useful food organisms.

Mixed wild algal cultures that grow in this system (Glancy method) were better foods than any combination of unicellular algae tested. Growth and survival were usually better than in larvae fed unicellular cultures.

LARVAL DISEASES, PREDATORS, AND COMPETITORS

Diseases, predators, and competitors were controlled by maintaining clean conditions. No physical, chemical, or prophylaxis treatment was used routinely except when water temperatures were over 28°C. Then, water was subjected to ultraviolet



Scallops in growing container.

light treatment. This treatment is reviewed by Loosanoff and Davis, (1963).

The most common disease problem was bacillary necrosis. This was treated with streptomycin (50 mg per liter) or with a wide spectrum antibiotic such as chloromycetin or polycillin. Care was taken in estimating dosage since antibiotics often caused the larvae to stop feeding for several days, and overdoses caused mortalities.

Arthropods often appeared in the larval cultures. These were controlled with tetraethyl pyrophosphate. Four drops in 60 liters of culture would usually kill all arthropods in less than an hour. Obviously this is a potent chemical and should not be used indiscriminately. Arthropods were also removed by screening. This method was preferred over chemical control.

Protozoans often appeared as a symptom of bacterial contamination. They were controlled by reducing the number of bacteria with an antibiotic.

As always, labor and space were considered as in a commercially-oriented culture practice. Therefore, it was usually more expedient to discard poor or sick cultures and start over rather than attempting treatment.

SETTING

Setting took place in 5-7 days, depending on food, temperature, and probably other environmental and genetic factors. The most obvious indication of spat stage was attachment by byssal threads to the culture container. The early juveniles have a well-developed foot with a heel-like byssal gland. The shell measures 175-200 μ at metamorphosis (Chanley and Andrews, 1971). This period, when the scallops were undergoing metamorphosis, was probably the most critical, and often heavy mortalities occurred.

Through early metamorphosis or setting, the scallops were kept in clarified water or in slowly flowing raw seawater. At this time vertical surfaces for attachment were presented to the setting scallops. These were panels of wood, mylar, or fiberglass that the juveniles fastened to by their byssus. Juveniles apparently preferred vertical surfaces and most were found clinging to the sides of the containers or the panels. As food requirements increased, flowing raw seawater was introduced. A screen of suitable size was placed at the overflow to retain scallops that were sucked into the overflow pipe while swimming. Juveniles were held in this manner until they reached 10-13 mm size, large enough to stay in ¼-in plastic screen.

When the juvenile scallops were moved into the field, they required confinement to prevent them from swimming away. A variety of enclosures were used. Floats anchored at the surface had severe fouling problems which reduced the flow of water. Additional problems of boat wakes and wave action, washing the scallops about in the floats and often causing a concentration in a corner with some loss due to smothering, were also encountered. Floats placed on the bottom had fewer problems but the scallops did not grow well.

The most successful growth and survival was in pens constructed of poles placed into the bottom with ½-in mesh plastic screen tacked around the outside of the poles. The pens were 10 ft square and 7 ft high. They were constructed in shallow subtidal areas.

Bay scallops grown in pens were brought to market size in 5-7 mo. Further, the adductor muscle was considerably larger than in scallops grown in floats. This may be due to

Juvenile scallops tagged and ready to be released.

the opportunity of scallops in pens to make vertical swimming excursions. The size of the adductor muscle is important since it is the only part of the scallop which is sold.

A series of tests were completed to assess the best depth to grow scallops. Little difference was found between depths if fouling, silting, and washing could be controlled. Experiments were also run to find the maximum optimum number of scallops per unit area that can survive and grow. Optimum growth and survival were found at 25 per sq ft of bottom area. However, the data suggest that 60-65 scallops per sq ft would be optimal economically, even though growth rates were less than optimum (Duggan, 1973).

PREDATORS

Although smothering is definitely the main cause of death, there are some serious predators. The rough oyster drill *Eupleura*, starfish, crabs (especially the blue crab, *Callinectes sapidus*) and various fish species are known predators of this species. No predator control methods were used in these experiments, but they should be considered in any commercial venture.

ACKNOWLEDGMENT

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MFR PAPER 1114

Crustacean Aquaculture in Middle America

HAROLD H. WEBBER

INTRODUCTION

This paper is designed to inform the reader regarding the technical and economic feasibility of establishing a profitable aquaculture venture in certain specific locations on the west coast of Central America.

The recommendations made here are predicated on the following basic premises:

1) The continuing paucity of high-value crustacean aquafoods in the expanding world markets demands that new sources of supply be developed.

2) An aquacultural production technology is maturing which will enable us to generate large volumes of shrimps at favorable cost.

3) The risks and rewards of a vertically integrated aquafood enterprise have been evaluated, and the business projections reveal an advantageous return on investment.

MARKETS

There exists a market for high-value crustacean aquafoods, including marine and freshwater shrimps, lobsters, and crabs, which is now unsatisfied and is likely to remain supply-constrained for the remainder of the century. This is a consequence in part of an increasing affluence in the highly developed industrial societies in the north temperate latitudes. This elevated economic status increases purchasing power, allowing for an improved standard of living and a widened consumer acceptance of less conventional and more expensive foods. Concomitant with the increasing demand, the traditional shrimp trawling industry has just about exploited the known wild populations of shrimps and prawns of the world's oceans, and we are now approaching the maximum sustainable yield (Cleary, 1970) obtainable from the wild resource. Additional significant supplies, therefore, we propose, must come from controlled, farm-raised production.

Dependence on the hunting and gathering arts is subject to the natural vagaries in the fluctuation of wild populations, and thus the market for aquafoods is often disturbed by oversupply or undersupply. On the other hand, a deliberately cultured product line that is produced in accordance with a reliable measurement of demand, and supplied into the market place on a continuous and scheduled regimen, can capture a significant market percentage and growth. The opportunity to service the HRI (hotels, restaurants, and institutions) market with controlled portions in a large range of sizes and forms under strict quality control with precise delivery schedules can be most readily exploited by an aquafarming business such as we are proposing here. Most successful high-wealth generating food industries owe their short-term achievements to the end that essential human needs are served or human desires are gratified. In the long run, however, the economic success will be in large part a consequence of the provision of high-quality products with an assurance of continuity of supply. To accomplish this goal at profitable economic levels, a sustained high productivity must be realized which in turn will be the result of wise management of the natural resources from which the bioindustry generates the wealth.

Harold H. Webber is the president of Groton BioIndustries Development Company, P.O. Box 517, Groton, MA 01450. This paper was originally presented at the symposium Aquaculture in the Americas held at the Inter-American Scientific Meeting, "Science and Man in the Americas," jointly sponsored by the American Association for the Advancement of Science (AAAS) and Consejo Nacional de Ciencia y Tecnología (CONACYT), México 18, D.F., México, 20 June to 4 July 1973.

Let us, then, first examine the needs and desires for crustacean aquafoods as they were expressed in the markets of the world for the past decade or so, and also as we can project the demand into the near and distant future.

Of the 69 million metric ton total world fisheries catch in 1970, approximately 1.6 million tons were crustaceans (Food and Agriculture Organization of the United Nations, 1971a). Of the crustaceans harvested, over 52 percent entered into world commerce, whereas somewhat less than one-third of the fresh and frozen finfish were traded in world markets. The mean landed value per pound of crustaceans was approximately five times that of finfish (Food and Agriculture Organization of the United Nations, 1971b).

The world catch of crustaceans generally has not kept pace with demand over the last decade. The U.S. supply of northern lobsters and of crabs has actually declined over this period, and the supply of spiny lobsters has increased relatively little and is now at only 54 million lb. The U.S. landings of American lobsters have been relatively constant over the past few decades at approximately 30 million lb, but over the past decade imports have declined because of the limited catch and the competition for the supply. The supply of crabs in the U.S. market is also seriously constrained.

The commercial shrimp trawling industry has realized considerable growth in the past 2 decades, in large part as a consequence of an apparently insatiable market demand for crustacean aquafoods in the developed markets of Europe, North America, and Japan. This demand has supported and justified a continuing search for new, previously unexploited wild populations of shrimps and prawns in the world's oceans, as well as a commensurate effort to improve fishing efficiency by the design and development of improved detection methods and catching gear. However, the significant success in increasing the catch year after year, has not kept up with the market demand, and consequently the selling price for shrimp in the developed world has responded with mounting annual increases. In the United States, shrimp sold at $1.05 per lb at retail in 1960, whereas by 1972 the mean selling price was $1.87 per lb. The United States demand has increased at a rate of approximately 6 percent per year, far exceeding the rate of population growth, so that the per capita consumption has approximately doubled, from about 1 to 2 lb over the last decade, while at the same time price has also increased 6 percent. Roedel (1973) predicted that the U.S. shrimp business would be at $1 billion at retail in 1973. Over the same period, the native U.S. shrimping grounds have been unable to sustain commensurate production. Therefore, the supply has had to be supplemented by imports, which in 1972 were 52 percent of the 488 million lb supply (Anonymous, 1973).

Cleary (1970) has estimated that shrimp harvests will level off within this decade, and that U.S. demand will exceed the world supply by 1980 if we depend on the wild resource. At present the U.S. market alone accounts for 1.1 million lb of shrimp a day.

There has also been a considerable increase in competition for the world supply of shrimps and prawns over the past few years. The U.S. and Japan now account for half of the world consumption. The European Common Market which has a combined population higher than that of the United States is beginning to compete vigorously with the United States and Japan for the already limited world supply.

Nonetheless, as long as the high demand and selling price for shrimps and prawns continues to increase, there will be a strong economic motivation to develop a supplemental source to the trawler-caught stocks. A maricultural system for rearing these animals in large numbers may provide a mechanism to accomplish this end. By the application of sound animal husbandry practices, we may expect to achieve an assurance for a reasonably constant year-round supply, thus freeing the market from the vicissitudes of a hunted resource.

Since a large portion of the world shrimp catch comes from tropical waters bordering on the shores of the developing countries of Latin America, Africa, and Asia, and the major markets are for the most part in the developed countries of the northern latitudes, an important contribution to a favorable foreign exchange balance is achieved by many developing countries in the American tropics.

CULTURE TECHNOLOGY

There exists new fundamental knowledge in aquatic biology, and an advanced comprehension of some of the interactions of the complex factors which contribute to successful high-intensity farm culture of penaeid (saline water) shrimps and macrobrachian (freshwater) shrimps. We at BioIndustries Development Company[1] have contributed to, and are in command of, this current aquatic animal husbandry technology and are now in a position to attempt to optimize the system in order to achieve a level of efficiency to ensure a profitable economic enterprise.

An essential component of the new technology is larviculture to produce seed shrimp for the stocking of nursery facilities. The staff of BioIndustries, led by Durbin C. Tabb, has made important contributions to the development of this technology (Tabb, Yang, Hirono, and Heinen, 1972). A hatchery facility is required in which gravid (egg-bearing) females, procured from the commercial trawler fleet, are induced to spawn in large tanks. The resulting larvae are reared through the several stages of larval growth on appropriate feeds that are cultured for the purpose, and environmental conditions such as water temperature, salinity, and light are critically managed to ensure high survival and growth rates.

The grow-out technique that we have developed involves a two-step process. First, postlarval shrimps are stocked in small nursery pools or tanks and grown in very high population densities. Intensive management practices provide that water quality and other environmental conditions in the nursery are maintained as close to optimum as is practicable. Since each individual is extremely small at this life stage, the ratio of biomass per unit water volume is quite low, and therefore the problems of sustaining a high-quality cultural environment are thereby reduced. The young, when fed appropriately, can be grown to about 2-3 g each in 45-60 days at the high stocking density maintained in the nursery, but at that size they must be thinned out. They are then stocked at the rate of at least 20,000 per acre into the final 10-acre grow-out ponds, and fed natural feed and supplemental formulated rations until they have reached market size in about 90 days.

Stocking density, feeding rates, predator and competitor control, disease and parasite management, and pond engineering and management have all been studied intensively by our staff as critical components of a total system. We have satisfactory empirical evidence that these matters are now amenable to practicable management control (Webber, 1970).

Various harvesting methods have also been studied in grow-out facilities of economic scale, and with mature populations of economic size. We are confident now that harvesting techniques or costs will not be a limiting economic factor, although we can anticipate further improvements and reduced costs over our present proven procedures.

SITING THE ENTERPRISE

The many considerations which impose themselves on the selection process for locating an aquaculture venture are discussed generically by Webber (1972). In the specific case of a shrimp aquafarming venture being considered here, certain priorities of a specialized consideration have been assigned to the criteria for site selection. The judgment employed in weighing the criteria is a consequence of considerable experience and understanding gained from our continuing effort to establish an economic shrimp culture system in Central America.

Based upon the high visibility reflected in demand of the penaeid shrimps in world commerce, and the consequent certainty of the acceptance of this produce in the major marketplaces of the world, we have placed our emphasis in this venture study on the marine shrimp species of the genus *Penaeus*. This emphasis then dictates that the aquafarm site must be supplied with an abundance of high quality saline water. Thus we are confined to a quest for a coastal zone site.

On the other hand, a rapidly growing technology has now matured for the culture of freshwater shrimps of the genus *Macrobrachium* (Fujimura and Okamoto, 1970). BioIndustries Development Company has been contributing for several years to this development and has grown out *Macrobrachium* in Honduras. This aquafood has not yet achieved significance in world trade, and is not yet caught from the wild or produced in culture in large quantities. However, macrobrachian shrimps are highly prized and command high prices as specialty aquafoods and, when available, compete favorably in the market with the penaeids.

Because of the advanced state of the culture technology, market acceptability, and the apparent favorable economics, we shall incorporate a consideration of *Macrobrachium* culture into this investigation, although in the economy of time we shall consider it secondarily to the penaeid culture venture. Nonetheless, the site selection demands of a macrobrachian aquafarm have been incorporated into our assignment of priorities of criteria for a penaeid aquafarm.

There are certain economies that can be realized from a dual farming venture. For example: whereas the penaeid grow-out facilities must contain saline waters and the macrobrachian culture ponds require freshwater, the same hatchery facilities can be utilized for both, since the macrobrachian spawning and larviculture requires a brackish water environment. Salinity control in the hatchery must be precise and thus provides for a range of levels. Thus, a hatchery located on an estuary that is subject to high tidal flushing, but

[1]Mention of trade names does not imply commercial endorsement by the National Marine Fisheries Service, NOAA.

is somewhat inland from the seacoast where good road access, power, labor, etc. may be actually more readily available than if the hatchery were located on the seashore itself, could serve both upstream macrobrachian ponds and penaeid ponds located on the tidal flats.

A single feed formulating and mixing facility may well serve both systems of culture. Common feed storage and bulk transport could be used. Similarly, one processing plant could handle the production of both farm complexes on essentially the same equipment and with the same labor. Finally, having various product forms from both genera of shrimps could extend the product line and thus provide greater leverage in the markets to serve a more comprehensive market strategy.

Penaeid shrimps as a genus are generally found in warm waters. They are frequently captured in the temperate zone; however, this latter catch is limited to the few summer months when water temperatures exceed 20° C. Even the U.S. coast of the Gulf of Mexico, with its vast shrimp populations, has winter water temperatures that are too low for shore-based culture systems. The species of shrimp that we have found most promising for culture are found in commercial quantities only in tropical waters. Mazatlán, Mexico, a major shrimp port on the Pacific Coast which is almost on the Tropic of Cancer, is about the northern limit of the Pacific white shrimp species upon which we have elected to concentrate our efforts. We view the Tropic of Cancer as the northern limit within which we can operate a shrimp aquafarm. The Tropic of Capricorn defines the southern limit within which economic shrimp aquafarming may be practiced. Another way to characterize this water temperature dependence is by the temperature range within which the tropical species of shrimps grow well. We can, for our present purposes, set the limits at 24-32°C, seeking the 28°C optimum mean temperature.

Photoperiod is an additional significant characteristic of the tropical environment which we feel has a strong influence on the physiology and on the behavior of tropical penaeids. Length of day can materially influence the reproductive cycle, and since this matter is of major concern to us, we feel that if we are to grow tropical species they can best be managed within the tropical zone.

Light intensity and quality, as well as the total solar energy impingement, are extremely important influences on primary productivity. In the environments which we expect to manage, these factors are most crucial ecological contributors to the natural nutritional support of high density populations, and they will appreciably reduce production costs by reducing the reliance on formulated rations that may have to be purchased. Here again the narrow annual range of fluctuation of the essential environmental parameters in the tropical latitudes provides the greater opportunity to realize other economic benefits, such as continuous year-round production by making wise use of these resources.

Therefore, an important high-priority site selection criterion, which we feel has to be satisfied before others are considered, is to locate the shrimp aquafarm in tropical waters. The tropical environments suitable for culture of the selected species and nearest to the North American markets may be found on the west coast of Central America.

The Pacific Coast of Central America is exposed to considerable tidal fluctuation (from as much as 16 feet in Panama to 9 feet in Puntarenas in Costa Rica, and about the same in La Unión, El Salvador). Furthermore, in the deep embayments of the west coast of Central America, Panama, Colombia, and Ecuador (a region which we shall identify as "Middle America"), which form such bodies as Golfo Dulce, Golfo Nicoya, Golfo Fonseca, Bahía de Jiquilisco, etc., there are shallow-water shores which in combination with the high tides result in wide intertidal zones. These coastal tide flats are generally occupied by mangroves. These regions make very attractive culture sites. Flowing through these wide intertidal mangrove swamps are many streams and rivers carrying the freshwater runoffs from the very high rainfall that occurs in the high mountain ranges close to the sea. These estuaries (esteros) provide elegant manageable waters from which the appropriate salinities can be selected.

We determined that the indigenous Caribbean species, which are identical or similar to Gulf of Mexico forms studied intensively in U.S. laboratories, are slower growing than certain Pacific Coast species of white shrimp, such as *Penaeus occidentalis*, *P. stylirostris*, and *P. vannamei*.

Whereas we now place a great deal of importance on the species of shrimp to be cultured, it is not sufficient alone to have identified them and learned how to rear them. It is also important from a business point of view to have ready access to large stocks of these animals from the wild, since we are not yet able to sustain lines of brood stocks in captivity. Until we have command over the reproductive cycle of penaeids, and can induce gametogenesis (production of eggs and sperm) at will, we must procure from the wild populations, gravid (egg-bearing females who are carrying spermatophores, or attached packets of sperm) shrimp, bring them into an appropriate hatchery facility, and induce them to spawn. The technical and cost efficiency of this stage of the culture system is in large part influenced by proximity of the hatchery to the port of a large shrimp fishing fleet, as well as the cooperation of the trawler captains.

This requirement is more readily satisfied on the Pacific Coast where the largest Central American, Panamanian, Colombian, and Ecuadorian commercial shrimp fisheries exist. The ports and processing plants that serve these shrimp trawling fleets are generally located where other resources are also available.

On the other hand, the consideration of access to wild gravid females imposes no constraint on site selection for a macrobrachian aquafarm. This genus of crustacean reproduces readily in captivity, and therefore can be reared wherever appropriate freshwater supplies are available, and where edaphic, climatologic, and the complex of economic factors can be satisfied. Consequently, we are justified in placing the macrobrachian aquafarm site selection secondary to that of the penaeid farm. Within a wide region along the Pacific Coast of Central America there is very high rainfall, and therefore an abundance of fresh water may be available within a practical distance of a selected penaeid farm site. The need for good quality fresh water for macrobrachian culture is such that the heavy use of pesticides (on a cotton farm for instance) might exclude the possibility of freshwater shrimp culture in the area. The presence of biocides in any culture waters, from whatever sources, of course, must be avoided.

Having thus generically defined the geographical, climatological, meteorological, and oceanological criteria as being best satisfied in a tropical environment, and having also imposed on the selection process certain more specific parameters such as the requirement for high tidal amplitudes in conjunction with extensive intertidal hectarage, as well as the requirement for access to gravid penaeid females of the appropriate species, we then are confined in our search for a site to the Pacific Coasts of Central America, Panama, Colombia, and Ecuador. At this time we are not considering Mexico because of the legal constraints imposed by limiting shrimp exploitation to cooperatives only.

Finding satisfactory ecological conditions, although extremely important, will not alone insure the success of the venture. Among the many other requirements which must be satisfied is the economics of bringing the product to market. Since we are contemplating a large-volume production of a frozen-food product, and we anticipate shipping the product primarily to North American, Japanese, and European markets, it is most likely that we will utilize modern refrigerated containerization techniques for oceangoing freight for shipping most of the production. We can anticipate that only small quantities of the fresh product will be airfreighted to distant markets or sold into domestic markets.

Since the ports serving the major shrimp markets in the United States are on the Gulf Coast and on the eastern seaboard and the routes to the European markets are Atlantic, a large portion of our ocean freight may pass through the Panama Canal. Therefore, on the basis of oceangoing transportation alone, proximity to the Panama Canal is an additional site-selection criterion which we should consider. There is, on the other hand, a growing practice of trucking the frozen, packaged product overland to Caribbean ports such as Puerto Barrios in Guatemala, or Limón in Costa Rica (Gross, 1973). We recognize that the Japanese and other developed Asian markets are equally accessible from any of the Pacific Coast countries of Middle America. While Ecuador, Colombia, and Panama are all significant exporters of penaeid shrimps to the U.S. market and have very attractive, ecologically favorable sites, we have elected to relegate these countries to a secondary consideration at this time either because we find their political and social climates less satisfactory, or because we are less familiar with them than we are with certain Central American countries.

Although BioIndustries Development Company has had reasonable experience, and still has an interest in an aquacultural business in Honduras, we find the political and economic risks too uncertain to justify investment at this time. Furthermore, Honduras has a very limited Pacific Coast shoreline on the Golfo Fonseca and no significant Honduran-based Pacific Coast shrimp fishery, and consequently no port facilities there. Thus, there would be very limited access to gravid females from commercial trawler fleets. This leaves the countries of Costa Rica and El Salvador as the acceptable candidates.

Both El Salvador and Costa Rica are in reasonably secure economic positions, although such matters fluctuate. Both countries are politically stable at this time. Costa Rica especially has a long history of democratic government, and has a large middle class with considerable purchasing power; Costa Ricans have the largest per capita income in Central America.

This relative affluence is reflected in the higher labor costs in Costa Rica, relative to other countries of Central America, but it is generally held widely that labor productivity there more than compensates for the slightly increased costs. The Costa Rican Investors Guide (Anonymous, 1972) quotes minimum wages that are favorable to a labor-intensive business.

In El Salvador, where labor is said to be very easily trainable and highly productive, some typical labor rates reported by Insafi (Instituto Salvodorena de Fomento Industrial) indicate that unskilled labor, as well as the skilled workers which we would employ, are paid at rates that will not burden a business. Other considerations such as investment incentives are very similar, and there is no important difference between the two countries. We have found that the Central American Bank for Economic Integration which is the development bank that fosters Central American Common Market growth, would look favorably on an aquaculture venture in Costa Rica and/or El Salvador.

Therefore, our site-selection field study may be limited to the Pacific Coasts of Costa Rica and El Salvador, and generally should be confined to what we judge to be an appropriate radius of the major shrimp port in each country. In El Salvador, we may investigate the mangrove covered intertidal zone around the port of El Triumfo where some 80 shrimp trawlers are based and regularly bring their catch to be processed and shipped. In Costa Rica the region around the port of Puntarenas provides the most attractive possibilities.

BUSINESS PLAN

The plan presented below is predicated on the premises noted at the outset of this presentation:

1) that there exist unsatisfied, receptive markets for the high-value products(s) that we propose to produce;

2) that the culture technology is sufficiently advanced to achieve high productivity, and that we have the knowledge and experience to apply this technology so as to achieve large-volume, low-cost production; and

3) that we have become aware, through empirical as well as theoretical evidence, of the essential components of a business system, including the imperative criteria for site selection, hatchery and nursery management, growout, harvesting and transport, processing a variety of acceptable product forms,

marketing into HRI and consumer outlets, and finance and agribusiness management.

An integration of the above-noted body of knowledge into the following business plan considers the known and calculable risks and presents the expected rewards. A consideration of the risks to aquaculture ventures has been presented by Webber (1973).

We shall here state, in reasonably conservative terms, our firm convictions based on experience and our reasonably assured expectations based on calculations, assumptions, and extrapolations. We intend to identify the bases of both classes of conclusions.

For the purpose of a venture analysis we shall concentrate our effort on the study of a Costa Rican site. This decision does not exclude El Salvador sites as potential locations for performing aquaculture businesses. We have elected to confine our investigation to the coastal regions within reasonable access to the port of Puntarenas, Costa Rica on the Gulf of Nicoya.

We have also chosen to confine our attention to the design of a business plan for the culture of marine shrimps of the genus *Penaeus*. This again does not mean that we do not hold in high regard the potential for freshwater shrimp culture business based on the genus *Macrobrachium*, but in the economy of our attention, time, and investment, we feel that it would be unwise to consider both genera simultaneously. We are, however, enthusiastic about a sequential approach which will bring a *Macrobrachium* venture into being soon after the *Penaeus* business has moved through its start-up phase.

We recognize that there is considerable commonality between the requirements for each, and we therefore have recognized the potential for the addition of a second genus. This consideration has influenced our restriction of the site selection to the Puntarenas region where upland freshwater and land resources appear to be favorable for macrobrachian culture. Such a culture can be integrated with the feed, harvesting, processing, and marketing sectors of the penaeid aquafarming business. In fact, it was because the fresh waters of the El Salvador site on the Bay of Jiquilisco are likely to be contaminated with pesticides that this region is relegated to a secondary choice.

The broad fringe of the extensive mangrove zone has several sites accessible by road and within easy communication with the port and other advantages of Puntarenas. The landward edge of the mangrove fringe, which is under government jurisdiction, can be leased under satisfactory terms of time and cost. The depth of the mangrove peat in this region has been observed to be in some cases from 3 to 4 feet, and it is underlain with heavy blue clay. These edaphic conditions in association with low labor costs of the region suggest that the cost of construction of pond levees will be low, and therefore we have estimated \$350 per acre as the capital requirement for the construction of grow-out facilities. This figure includes sluiceway, gates, harvest sump, and drainage canals.

Although we present this venture plan with a high level of confidence in its potential success, and with high levels of assurance that our assumptions are reasonable and wise, we advocate a pilot operation as the initial phase of a development. We emphasize this recommendation because it has been the experience of most agribusiness that technology transfer cannot be made readily from one ecological site to another without considerable adaptation of those components of the system which are site sensitive. The effects of water qualities, meteorological variables, and other environmental influences on natural productivity, as well as the social, political, and cultural variables that influence the way business can be conducted in a given environment, can best be determined and understood empirically.

We therefore recommend that a pilot production farm, plus the supporting facilities, be operated for a sufficient period of time to prove (test) the technical and economic aspects of a proposed plan. We can anticipate that a pilot or start-up period may require 18-24 mo. It should be recognized that this first-phase period is not a research and development effort, but is primarily a trial of an existing technology being applied to a new environment. Whereas we may expect additional information to accrue from this experience which will enable a closer approach to optimization, the primary purpose of a pilot period is to generate engineering and operating data within the specific environment to enable an economic and practical scale-up of the system to full production. However, since we may expect a 90-day grow-out period, one may achieve a harvest during the first year. If this harvest confirms the assumptions, one may consider this to provide sufficient engineering and operating data to support the decision to proceed toward full-scale production promptly.

Alternatively, one may elect to accomplish several additional harvests before scale-up, but it is our judgment that the checkpoint need not be deferred beyond 24 mo after day one.

It is our best judgment at this time, based upon our previous experience in the management of aquafarms and our understanding of the tasks to be performed, that a modular farm of about 200 acres represents a unit which can be managed by a competent farm foreman and a crew of laborers. This concept of a module should be factored into a plan, and may be judged to represent a second checkpoint on the time/size scale. Whereas this size is dictated by management-labor, feed storage, harvesting, etc., it does not prove to be of sufficient size to be economically viable for an investment program. It could, however, be a very good size for a single owner-manager operation if it were properly supported with juveniles for stocking, feed, and other such critical inputs. We make reference to this matter here primarily to indicate a land unit that should have sufficient production to justify a consideration for its separate existence. By this we mean that even though we are advocating here an aquafarming venture that will ultimately utilize 2,000 acres of water for production, we are saying that these need not be contiguous acres, but can be developed in separate increments of about 200 acres each. As long as these separate farms are within an appropriate radius of both a farm headquarters which can supply juveniles for stocking grow-out ponds, technical pond management backup, feed supplements, etc. and a processing plant which will prepare the product, they can be integrated into a system.

We have concluded that three such farms, or 600 acres of grow-out production, constitutes a sufficient business scale to stand alone as an industrial entity. This will generate sufficient income to provide an acceptable return on investment. However, at this point on the growth curve of the enterprise, a small processing plant is warranted. We propose a labor-intensive processing operation.

This was done because we are convinced that there are considerable economic advantages to be realized from a fully integrated enterprise in which processing and marketing are operated concomitantly and coordinated with production.

We have not at this time isolated processing and marketing as a separate profit center although this can readily be done. In a vertically integrated, balanced system, it is axiomatic that all major components should be intimately coordinated and operated at a flux-equilibrium if we are to achieve the advantages of optimization of the technical and economic sectors of the system. In order to achieve this condition we have carried our analysis to the 1,000- and 2,000-acre production scales. This will provide an input into the processing plant, and subsequently into the market place, of a sufficient volume of product to allow for optimization of the food processing technology and a sophisticated marketing program. It is anticipated that a high degree of processing efficiency can be achieved employing a wise mix of hand labor and mechanization to enable efficiency, control of quality, versatility in product form, and a certain amount of social profit by the creation of jobs in a society having excess labor.

Since we have not at this time achieved optimization of the many influences on production cost (such as feed formulation versus cost per pound of production; pond management to enable high natural productivity so as to provide low cost forage upon which the shrimp can grow without complete reliance on formulated rations; reduced mortality by reduction of environmental stress, predation, disease, etc.) we cannot categorically state yields and consequent costs. However, for the purpose of this analysis we have elected to use what we judge to be a conservative yield of 3,000 lb per acre per year, which we have already achieved.

We expect, after the pilot phase has been completed, to acquire sufficient additional understanding of the performance of the system in situ to realize higher yields such as 3,500 or 4,000 lb per acre per year.

Similarly, we have used a feed conversion ratio of 2.5:1 and a cost per pound of formulated pelletized ration of 14 cents/lb. We judge these to be very conservative figures.

The prospect of the establishment of a large number of successful crustacean aquafarms in the Middle American costal and freshwater environments within the next few years is not very great. On one hand the high capital investment required to establish the reasonably large-scale facilities needed to be economic and the limited number of sites that can provide favorable competitive advantages, on the other, will in my judgement, curtail the number of profitable undertakings. Furthermore, the level of business management sophistication and technical know-how will confine such activities to a very few.

One mechanism to achieve the advantages of economic scale, while at the same time enlisting the involvement of a large number of small landholders, may be through farm cooperative organizations which can provide technical assistance and engineering guidance for pond design and construction as well as coordinate the function of juvenile production for stocking privately owned grow-out facilities, feed production and distribution, and even a custom harvesting service.

Alternatively, a private enterprise organization can provide the services that can be provided by the cooperative noted above to individual small-scale farmers and can justify its efforts by contracting for the production to be processed and marketed from a central facility. This would allow the associated growers to operate individual farms, which would make them, in effect, correlative with captains of privately owned trawlers selling their catch to a central processing plant.

Because of the high production costs and the commensurate high selling prices commanded by these high-value products, crustacean aquaculture in the Middle Americas is not likely to make a significant contribution to freedom from hunger for those people in the developing world where dietary protein deficiencies are prevalent. It may, however, make a significant contribution to economic development by generating foreign exchange, contributing to growth of infrastructure, and, most importantly, by providing employment in the rural sectors of certain Middle American societies.

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